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Plasma Sound Source Basic Research
Annual Summary Report
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1. INTRODUCTION

The plasma sound source (PSS) is an acoustic source used to generate high intensity low frequency sound. ARL:UT is conducting a research and development program for the PSS that has both basic research and engineering development components. The basic research component provides the models and the fundamental physical understanding for the PSS, while the experiments and the large scale hardware developed in the engineering effort provide a testbed of experimental data and equipment that allow the models to be tested for validity. The modeling capability and the experimental hardware that have been developed at ARL:UT have produced substantial improvements in plasma (spark) sound source technology. Previous research into the hydrodynamic properties of the PSS (ONR Grant 0018) has provided the acoustic models capable of predicting array signatures and acoustic characteristics of large numbers of interacting PSS elements. Furthermore, statistical thermodynamic models were developed to model the internal filling plasma which gave insight into some aspects of the energy loss mechanisms associated with the PSS. These models provided little detailed understanding of the breakdown of the water and the development of the arc channel or the electrical properties of the arc in even the older simpler electrode configurations that had been studied. This research effort is intended to address this very important gap in our understanding. Current efforts of research focus on those issues which will permit the source to be used as a practical sound source in a long range anti-submarine warfare (ASW) system. The principle anticipated advantages are that the source will be compact with a light weight end. This would allow the deployment of a large array or high speed towing of this array which cannot be done with the current sources.

The basic research component of this ONR sponsored program is focused on three areas of research:

- Dielectric breakdown of salt water.
- A study of the electrical and acoustic properties of multiple gap electrodes.
- Development of detailed model of the plasma arc and, if possible, the coupling of this model to the non-spherical bubble formation in the initial stages of the arc formation and energy delivery.

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These areas were selected as the key areas where new models and understanding are needed to move the plasma sound source from a laboratory curiosity to a practical source.

2. DIELECTRIC BREAKDOWN

The development of understanding and modeling of the dielectric breakdown in water is a major factor in the process of creating efficient spark-sources. This process is fundamental to the arc-formation which is the transduction element of this source. The need to understand the breakdown process is essential for practical spark source because the electrical resistance of an arc is proportional to its length. The resistance of an arc must be larger than that of the cable so that the majority of the electrical energy is dissipated in the arc. During this past year, experiments were conducted to establish some of the properties of the breakdown mechanism. Experiments were conducted with a point-to-plate electrode with characteristic fields of 43 kV/cm. The static pressure of the fluid was varied from 0 to 150 psi. The fluid conductivity for most of the experiments was 6.8 mS although some data was taken with a higher conductivity of 32 mS. Furthermore, the discharge circuit impedance was modified. These results showed that the breakdown characteristics of salt water were strongly dependent on the circuit impedance. When the circuit impedance was raised by adding 5 ohms of series resistance, a strong decrease in the ability of the circuit to break down the dielectric as the pressure increased was observed. Hence the effective dielectric strength of salt water increased. When this resistance was removed, the breakdown strength of the salt water showed an increase in strength up to 60 psi. Above 60 psi, little change in the breakdown strength was observed. In addition, the lower conductivity solution required less energy to break down than the higher conductivity solution.

In addition to this experimental effort, a theoretical effort has also been undertaken. The goal of this effort is to improve the understanding of the physical mechanisms involved in the breakdown process of the water. The sparks made in air look very similar in high speed photographs to the sparks made in water, so it was attempted to use gas discharge parameters to explain the breakdown of water. Unfortunately, many difficulties were encountered. First, the kinetic theory used for gases cannot be applied to water since it is many orders of magnitude denser, so electron avalanches which are a central part of the gas theory are a useless concept in water. A single free electron in water is difficult to model; even conduction in water is modeled by hydrodynamics, ignoring the discrete nature of the constituent particles that make up water.

Due to the lack of tractable models, thermal models were considered for this phenomenon. Thermal models are those models which depend on ohmic heating to modify the dielectric medium, either locally or globally reducing the density of the water sufficiently to allow avalanche ionization to occur. Our first efforts will be to explain the observed features of the leaders formed before breakdown. Second, it is hoped that some way may be found to model the dynamic behavior of the leader phase self-consistently. The high electric field

results in vaporization, or density reduction in the water which is sufficient to allow avalanche ionization to occur within the leader. Very little in the existing literature can shed any light on the observed relationship between the electrical discharge circuit internal impedance and the change in the breakdown strength as a function of ambient pressure.

Recent research by Kunhardt and Jones suggests that the formation of the leaders may be initiated by the nucleation of bubbles in the water which then allow the avalanche ionization to occur internally in the reduced density of matter inside the bubble.[1,2,3] If these models prove to be correct, they would be an important part of the breakdown model needed for the PSS. The model needed for the PSS, however, must describe the pre-breakdown energy consumption and the voltage-current relationships for a type of electrode geometry or multiple electrode geometry. At present these features are not described in these new models.

3. MULTIPLE GAP ELECTRODES

Because of the current lack of analytical models to assess the breakdown, any effort to increase the arc length that is created at a given voltage is necessarily empirical. Experimental results from anther PSS project have recently been made available for analysis. The standard electrode design used previously had a single gap. In some recent experiments, it was discovered that using "floating " conductors between the anode and the cathode of a given electrode could allow the breakdown of a gap with less energy consumed for the process. Tests with several different electrodes showed that reasonable improvements could be achieved with widely spaced gaps. In these experiments, each gap created an individual bubble. The bubbles were spaced far enough apart that their behavior could be considered hydrodynamically independent. The total bubble energy in the cavities for two cavities was about twice the energy in the cavity of a single bubble. Although the improvement in bubble energy is a major reason for using this type of electrode, the amount of energy to break down multiple gap electrodes was observed to increase as the number of gaps increased. This aspect of the multiple gap behavior will continue to be the main focus of the research, because of the implications in practical systems. It will rely heavily on experimental data, and this project will be closely coordinated with the theoretical studies being performed for the dielectric breakdown.

4. INHOMOGENEOUS HYDRODYNAMIC MODEL

This portion of the research effort has been necessarily delayed because of the information that is required in this effort especially with regard to initial conditions, and the specific initial arc geometries that were needed from the dielectric breakdown research. The hydrodynamic model will utilize very sophisticated hydrodynamic models already developed at Los Alamos Laboratories for explosions. These results will be compared against

experimental data to determine whether all of the key features of the plasma are being modeled. The results from these models will also be used to determine what simplifications can be made to yield more tractable and physically insightful models which will give the electrical properties of the arc. Due to the very specialized nature of the qualifications needed for this research effort, ARL:UT has experienced some difficulty in staffing this position. It is expected that this position will be filled in the near future.

5. PUBLICATIONS IN PROGRESS

There are currently three papers in progress which are expected to be submitted to the Journal of the Acoustical Society of America:

- "Interactions and Acoustic Characterization of Multiple Spark-Generated Bubbles; Part I," Jeffrey A. Cook, Austin M. Gleeson, and Robert L. Rogers

- Interactions and Acoustic Characterization of Multiple Spark-Generated Bubbles; Part II, Jeffrey A. Cook, Austin M. Gleeson, Randy M. Roberts, and Robert L. Rogers

One paper has already been submitted to JASA and is currently under revision:

- "Energy Partition of Underwater Sparks," Randy M. Roberts, Jeffrey A. Cook, Austin M. Gleeson, Thomas Griffy, Robert L. Rogers

The students who are currently working on the plasma sound source project are:

- James Espinosa (PhD student in Physics)

- Mack Galloway (Senior undergraduate, Physics)

REFERENCES

1) H.M. Jones, and E.E. Kunhardt, "The Influence of Pressure and Conductivity on the Pulsed Dielectric Breakdown of Water," IEEE Trans. Dielectrics and Elect. Insul. (to be Published).

2) H.M. Jones, and E.E. Kunhardt, "Pulased Breakdown of Pressurized Water and Salt Solutions," J. Appl. Phys. (to be Published)

3) H.M. Jones, and E.E. Kunhardt, "Development of Pulsed Dielectric Breakdown in Liquids," J. Phys. D: Appl. Phys. (to be Published)